Forest Ecology and Management 260 (2010) 2045–2052

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Integration of Northern spotted owl habitat and fuels treatments in the eastern Cascades, Washington, USA

William L. Gaines[a,*], Richy J. Harrod[a], James Dickinson[b], Andrea L. Lyons[a], Karl Halupka[c]

[a] USDA Forest Service, Okanogan-Wenatchee National Forest, 215 Melody Lane, Wenatchee, WA 98801, USA
[b] USDA Forest Service, Pacific Northwest Research Station, 1133 North Western Avenue, Wenatchee, WA 98801, USA
[c] USDI Fish and Wildlife Service, Wenatchee Field Office, 215 Melody Lane, Wenatchee, WA 98801, USA

ARTICLE INFO

Article history:
Received 28 June 2010
Received in revised form 3 September 2010
Accepted 6 September 2010

Keywords:
Northern spotted owl
Fuels treatment
Analytical hierarchy process
Logistic regression
Range of variation
Eastern Cascades
Washington

ABSTRACT

The restoration of natural fire regimes has emerged as a primary management objective within fire-prone forests in the interior western US. However, this objective becomes contentious when perceived to be in conflict with the conservation of rare wildlife species. For example, the integration of fire ecology in disturbance-prone forests of eastern Washington with the recovery of the Northern spotted owl has been described as a management dilemma. We intersected modeled spotted owl habitat with mapped priority fuels treatment areas in order to determine the magnitude of the potential conflict between fuels management and owl conservation. Our results show that there is considerable overlap within dry forests between high suitability spotted owl habitat and moderate-high priority fuels treatment areas (34% overlap). However, there is also considerable overlap of lower suitability spotted owl habitat with moderate-high priority fuels treatment areas (35% overlap) providing opportunities to accomplish multiple management objectives if one considers a landscape perspective. We propose that a conservation strategy for the Northern spotted owl in the eastern Cascades consider the following: emphasize landscape restoration of dry forests within which spotted owl habitat is embedded; landscapes considered for restoration need to be large enough to accomodate the effects of fire disturbances and still retain sufficient habitat to support spotted owl populations; and include adaptive management allowing for adequate monitoring and feedback for managers to make needed adjustments.

Published by Elsevier B.V.

1. Introduction

Because of the role that fire plays in many ecosystems, fire management is central to the conservation of biodiversity (Myers, 1997; Driscoll et al., 2010), and restoration of natural fire regimes has been suggested as a coarse filter for conservation (Agee, 2003a; Prather et al., 2008). However, several authors have identified potential conflicts between the restoration of fire regimes and the conservation of rare or protected species (Landsberg and Lehmkuhl, 1997; Myers, 1997; Agee, 2003a; Prather et al., 2008). The interactions between fire, fire management and maintaining habitat for rare or protected species is of particular interest within the fire-prone forests of the interior west (Agee, 1993; Brown et al., 2004; DellaSala et al., 2004; Hessburg et al., 2005; Noss et al., 2006; Prather et al., 2008).

Conservation strategies for the Northern spotted owl (*Strix occidentalis caurina*) within the east-Cascades physiographic province need to address the potential effects of wildfire on habitat (Agee and Edmunds, 1992; Bond et al., 2002; Collins et al., 2010; Courtney et al., 2008; Davis and Lint, 2005; Everett et al., 1997; Gaines et al., 1997; USFWS, 2008). However, considerable debate is occurring over the risk that fire poses to spotted owl recovery and how recovery actions should address fire risk (Hanson et al., 2009a,b; Spies et al., 2009). Understanding the spatial overlap between areas that provide spotted owl habitat and areas that are priority for fuels treatments would help managers determine the degree of potential conflict and design options for resolving the conflict (Prather et al., 2008; Collins et al., 2010).

Northern spotted owl nest sites in the eastern Cascades have high canopy closure, multiple canopy layers, and occurred in mid-late successional forests composed of grand fir (*Abies grandis*), Douglas-fir (*Pseudotsuga menziesii*), or Western hemlock (*Tsuga heterophylla*) forest associations (Buchanan et al., 1995). Spotted owl "neighborhoods" around nests have multi-layered canopies, and more small and large trees than unoccupied stands (Everett et al., 1997). Tree density and the proportion of shade tolerant tree species both increased significantly in spotted owl nest sites since Euro-settlement (Everett et al., 1997). Exclusion of fire from dry and mesic forests has increased suitable habitat conditions for spotted owls, but simultaneously resulted in greater risk of habitat loss due to fire (Buchanan et al., 1995; Everett et al., 1997). Everett et

* Corresponding author. Tel.: +1 509 664 9232; fax: +1 509 664 9280.
E-mail address: wgaines@fs.fed.us (W.L. Gaines).

0378-1127/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.foreco.2010.09.011

al. (1997) suggested that while vegetation manipulation to reduce fire hazard may create less optimal habitat for the Northern spotted owl, habitat effects from vegetation treatments should be weighed against the risk of stand replacement fires and the loss of nesting and roosting habitat over large areas. Over 50% of the Northern spotted owl nest-sites in the eastern Cascades of Washington occur within dry and mesic forests (Gaines, 2001), which are at risk of uncharacteristic fire (Agee and Edmunds, 1992; Everett et al., 2000; Hessburg et al., 2007).

Several authors have suggested that fuels reduction occur in and around Northern spotted owl habitat to reduce the risk of habitat loss from wildfires (Agee and Edmunds, 1992; Everett et al., 1997; Gaines et al., 1997; Davis and Lint, 2005; Lee and Irwin, 2005; Ager et al., 2007; Lehmkuhl et al., 2007). Fires have had the single largest impact on the amount of spotted owl habitat in the eastern Cascades of Washington since the implementation of the Northwest Forest Plan in 1994 (Halupka, 2001; Davis and Lint, 2005), and have been a factor affecting the availability of old forest habitats in the Pacific Northwest (Spies et al., 2006; Healey et al., 2008). Limited research has been conducted on the direct effects of fires on spotted owl habitat. Wildfires that create large patches of high severity burned area appear to have a negative impact on habitat (Elliot, 1985; MacCracken et al., 1996; Gaines et al., 1997; Bond et al., 2009). High severity wildfire alters the forest structure associated with spotted owl nest and roost sites: high canopy closure, large-live tree basal area, and total live-tree basal area (Gaines et al., 1997; Roberts, 2008; Bond et al., 2009). Low to moderate severity wildfires may have little or slightly positive impacts on spotted owls (Bond et al., 2002; Roberts, 2008; Bond et al., 2009).

Previous studies have used fire modeling to evaluate treatment options that reduce fire risk while minimizing the loss of spotted owl habitat from either treatments or fires (Ager et al., 2007; Lehmkuhl et al., 2007; Kennedy et al., 2008). Our study differs in that we included a process to map and prioritize areas for fuels treatments and we built an empirical model of Northern spotted owl habitat. Thus our objectives in this paper were to (1) develop a quantitative approach to identify habitat for the Northern spotted owl, (2) overlay spotted owl habitat identified by our habitat model onto areas we identify as high, moderate, and low priorities for fuels treatments to determine the degree of spatial congruence, and (3) based on our findings, suggest approaches to integrate objectives of protecting habitat for the Northern spotted owl and the restoration of dry-forest landscapes.

2. Methods

2.1. Study area

The study was conducted on the eastern slope of the Cascades Mountains in Washington State, on the Wenatchee portion of the Okanogan-Wenatchee National Forest (Fig. 1). The study area was about 875,000 ha, covering an area 45 km east from the crest of the Cascade Mountains and 225 km north to south. Elevations of Northern spotted owl locations ranged from about 350 m to 1500 m. Mean annual precipitation is about 25 cm on the eastern edge of the study area and 190 cm on the western edge (Lillybridge et al., 1995). The wetter portions of the forest are characterized by Western hemlock, silver fir (*Abies amabilis*), and moist grand fir, while the dry forests are characterized by Douglas-fir, dry grand fir and ponderosa pine forests (Lillybridge et al., 1995).

2.2. Northern spotted owl location data

Protocol surveys for Northern spotted owls have been on-going since 1990. These surveys have been conducted as part of two major spotted owl demography studies, referred to as the Cle Elum and Wenatchee study areas (Anthony et al., 2006). In addition, localized surveys have been conducted to assess the impact of proposed projects on spotted owls. These surveys followed existing protocols (Forsman, 1983; USFWS, 1992) and have been implemented over an estimated 75–80% of the available habitat on the forest (USFS, 1997).

We used survey information to create a spatial datalayer of spotted owl activity centers. Site status was classified on an ordinal scale from resident single, pair, or pair with young and was based on the survey protocol (Forsman, 1983; USFWS, 1992). For activity centers with more than 1 survey year we used the most recent survey data with the highest site status to determine the location of the activity center. In this way, we identified a single location for each activity center, assigned it the highest level of status, and used this to produce a map of activity centers that we used in our spatial analyses. This resulted in a database of 227 activity centers well distributed across the study area (Fig. 1), of which 124 were classified as a reproductive site (pair with young).

2.3. Habitat variables

We used published literature from local studies to determine a set of variables that we thought would best describe spotted owl habitat and also be of use to managers designing forest treatments in and around Northern spotted owl habitat. We chose to distinguish habitat based on groups of forested plant associations (Lillybridge et al., 1995) in part based on Buchanan and Irwin (1998) and also because of different disturbance regimes that influence the sustainability of spotted owl habitat in eastern Washington (Agee, 1993; Agee and Edmunds, 1992; Everett et al., 1997; Agee, 2003b). We grouped these forested associations into dry forest and wet forest groups (see USFS, 2001 for detailed descriptions of these groups), excluding all of the subalpine fir (*Abies lasiocarpa*), whitebark pine (*Pinus albicaulis*), mountain hemlock (*Tsuga mertensiana*), and subalpine larch (*Larix lyalli*) forested plant associations. We excluded these high elevation forested plant associations because they do not provide habitat for spotted owls (Buchanan et al., 1995; Everett et al., 1997). We used canopy closure as it is commonly used to describe spotted owl habitat (Davis and Lint, 2005; Tari, 2007) and Buchanan and Irwin (1998) identified canopy closure as one of several variables that provide important functions for spotted owls. We also used tree size to model spotted owl habitat as it again was identified as an important variable in local habitat studies (Buchanan et al., 1995; Everett et al., 1997). We included two topographic variables: aspect and slope. Aspect was an important variable in mapping fuels treatment priority areas (see Section 2). Singleton et al. (2010) found slope position to be an important variable in characterizing spotted owl activity centers and in distinguishing spotted owl activity centers from barred owl activity centers. Thus, we categorized aspect and slope position variables to be comparable to Singleton et al. (2010). Based on these premises, we identified a set of seven *a priori* models to evaluate against our spotted owl activity center and reproductive site location data (Table 1):

1. Forestgroup + canopy closure + treesize + aspect + slope
2. Forestgroup + canopy closure + treesize + slope
3. Forestgroup + aspect + slope
4. Canopy + treesize + slope
5. Canopy + treesize
6. Forestgroup + aspect
7. Aspect

We chose from available GIS datalayers to map the variables used in the habitat analyses. Table 1 shows the data sources used

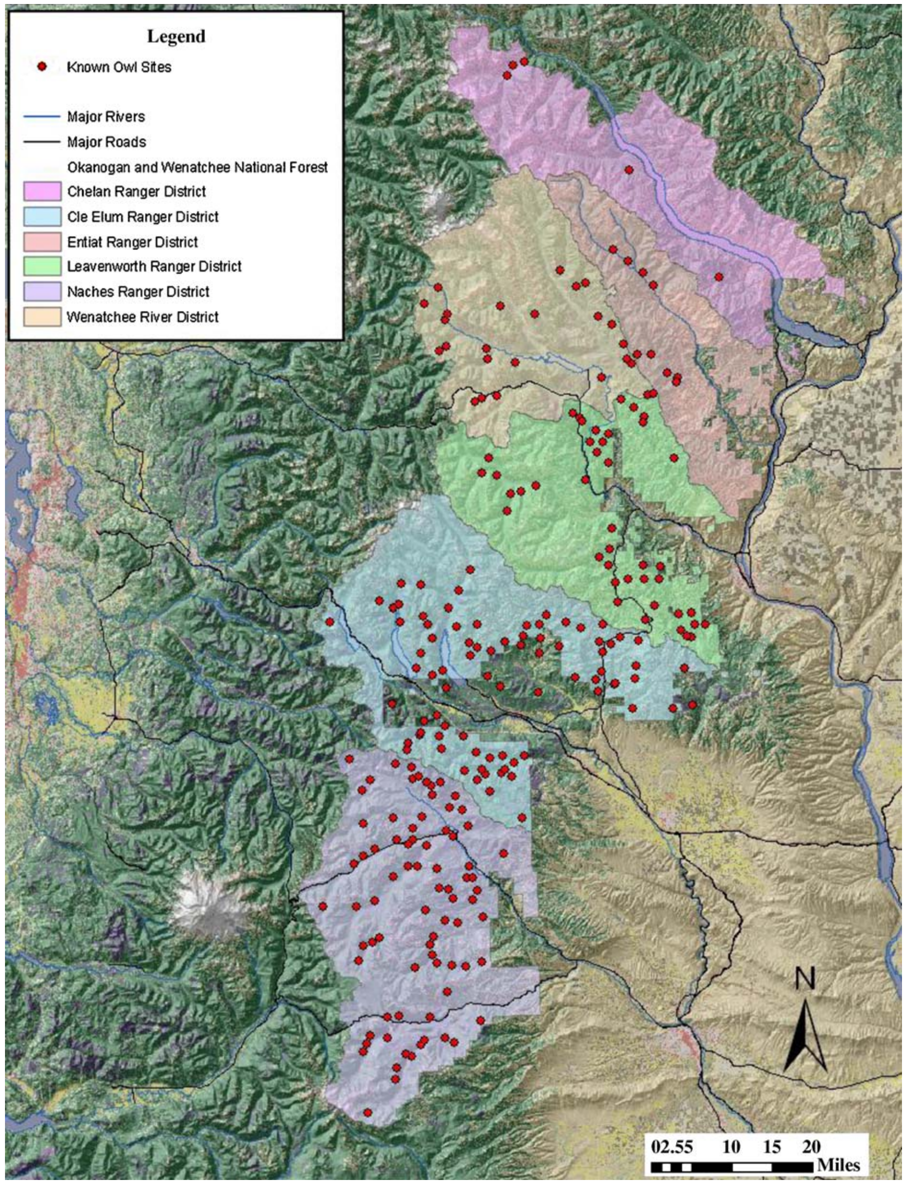

Fig. 1. Map showing the general distribution of Northern spotted owl activity centers on the Okanogan-Wenatchee National forest, eastern Cascades, Washington.

Table 1
Data source for the variables used to model habitat for the Northern spotted owl and identify priority areas for fuels treatments in the eastern Cascades, Washington.

Model variables	Categories	Data source
Forest group	Dry Forest Wet Forest	Based on Plant Association Groups data-layer for the east-Cascades Province
Canopy closure	High = > 60% canopy closure Moderate = 40–60% canopy closure Low = 10–40% canopy closure	Interagency Vegetation Mapping Program
Tree size	Small = <10″ QMD Medium = 10–15″ QMD Large = >20″ QMD	Forest-wide tree structure datalayer developed from Nieman (1998)
Aspect	North = 316–45° East = 46–135° South = 136–225° West = 226–315°	30 m digital elevation model re-sampled to 25 m resolution
Slope	Flat = < 5° Gentle = 5–14° Moderate = 15–25° Steep = > 25°	30 m digital elevation model re-sampled to 25 m resolution

for each variable and how the variables were categorized. We did not calculate metrics of spatial habitat configuration commonly produced in programs such as FRAGSTATS (McGarigal and Marks, 1993) because we wanted our approach to be: the same as is commonly used by managers to map and evaluate spotted owl habitat, compatible with the approach used to develop fuel treatment priorities map (e.g., pixel based), and easily interpreted by managers. We applied the majority filter function in ARC GIS to remove isolated pixels identified as spotted owl habitat.

2.4. Spotted owl habitat modeling

We used binary logistic regression of habitat variables at 227 Northern spotted owl activity centers and 124 reproductive sites, compared to 240 random points to evaluate habitat models. The 240 random points were used to assess habitat availability within the study area for comparison to the known spotted owl activity centers and known nest sites. Random sites used in our analyses did not overlap pixels identified with a spotted owl activity center nor did they occur in high elevation forested plant associations that did not provide spotted owl habitat (see Section 2.3). We performed logistic regression analyses with Akaike's Information Criterion (AIC) (Anderson et al., 2001; Anderson and Burnham, 2002; Burnham and Anderson, 2002) to determine which model best approximated the structure of our dataset. We addressed correlations among covariates by removing variables with a high degree of correlation ($r > 0.50$).

We calculated the relative importance of each model variable (Burnham and Anderson, 2002). Those variables with the largest Akaike weights (w_i), summed for each model where the variable was used, are considered the most important.

To test the stability of our selected model, we ran the best model ($\Delta_i = 0$) through a jackknife cross-validation procedure. We removed 10 randomly chosen data points from the spotted owl activity center and reproductive site dataset and ran the new dataset through the selected model, repeating this procedure 10 times (Dunk et al., 2004, Gaines et al., 2005). We looked for differences in fitted functions between those from the cross-validation and those from the entire dataset. Large differences would indicate models that were not stable and not useful for prediction in new areas (Dunk et al., 2004).

We used variables from the model with the highest evidence ratio to map the relative suitability of Northern spotted owl habitat and to derive categories of habitat suitability. We assumed that areas mapped as high suitability had greater conservation value to spotted owls than areas mapped as low suitability because they had more of the habitat variables positively associated with spotted owl reproductive sites. We used GIS to classify each 30 m pixel into habitat suitability classes.

2.5. Fuels treatment prioritization

We mapped and prioritized forest fuel treatment areas for the Okanogan-Wenatchee NF using the analytical hierarchy process (AHP; Saaty, 2001). The AHP allows the user to break complex problems/decisions into their constituent parts and each part is then individually compared to other parts. In the case of where to treat forest fuels, there are many factors to consider and spatial representation of each important factor becomes difficult. We used the ArcGIS AHP-Extension to take spatial information in grid form, multiply assigned weighting factors by the value of key variables at each grid cell, and then summed up the products of all the input grids creating a new grid with this sum as the cell value. We chose the following key variables: fire regime (1–5; Interagency Fire Regime Condition Class guidebook, Version 1.3.0), fuel model (1–13; Anderson, 1982), aspect (1–360° and flat), and elevation (5 categories). These variables were readily available in GIS (Table 1) and were considered to be important in determining what to treat and where treatment was operationally feasible. We solicited expert judgment from 10 fuel specialists and fire ecologists to develop weighting factors from 1 to 9 for each of the key variables. We input these weighted values into a matrix which represented the scale of importance among factors. The weights that resulted from this matrix were: fire regime 57%, fuel model 32%, aspect 7%, and elevation 4%. The final map represented low, moderate, and high priority treatment areas based on the final scores from the AHP process.

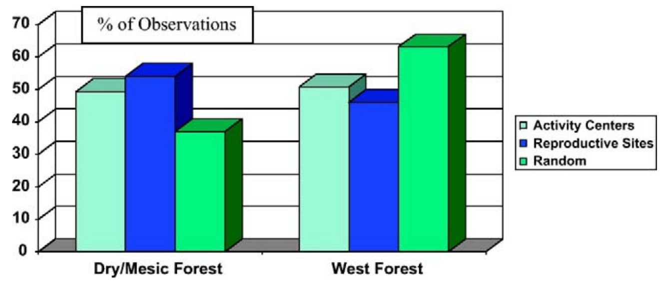

Fig. 2. The broad forest groups associated with 227 Northern spotted owl activity centers, 124 reproductive sites, and 240 random locations in the eastern Cascades, Washington.

2.6. Spotted owl habitat suitability × fuels treatment priority

We overlaid the spotted owl habitat and fuels treatment spatial data to create a matrix showing the amount and proportion of high, moderate and low habitat suitability that fell within high, moderate, and low treatment priorities. This was completed through a pixel by pixel level comparison across the study area.

3. Results

Logistic regression results showed a combination of variables were important in describing habitat at spotted owl activity centers (Table 2) and resulted in two models ($<2\Delta_i$) that best described the spotted owl activity center dataset. Evidence ratios for the other models were generally exponentially greater than the chosen models (Table 2). Of the two best models for the activity centers, model AC2 was the most parsimonious model, containing variables forest group, canopy closure, tree size and slope. All variables in this model were relatively important ($\sum w_i \approx 1$). The second best model (AC1) also had substantial empirical support and included the same variables as model AC2 with the addition of aspect (Table 2). Again, most of the variables were relatively important, however aspect was not ($\sum w_i \approx 0.40$).

Logistic regression results showed a combination of variables were important in describing habitat at spotted owl reproductive sites (Table 2). However, only one model (R2) best described the reproductive site dataset as all other models had Δ_i that were >2. Evidence ratios for the other models were generally exponentially greater than the chosen models. The "best" model contained variables forest group, canopy closure, tree size, and slope, and all variables were relatively important ($\sum w_i \approx 1$) (Table 2). Aspect was even less important in the reproductive site models ($\sum w_i \approx 0.23$) compared to the activity center models.

Based upon the results of models AC2 and R2 (Table 3), spotted owl activity centers and reproductive sites were generally positively associated with dry forests (Fig. 2), high (>60%) canopy closure (Fig. 3), large tree sizes (>15″ QMD) (Fig. 4), and moderate slopes (16–25°) (Fig. 5). Conversely, they were generally not associated with canopy closure <60% (Fig. 3), medium tree size

Table 2
The logistic models used to describe Northern spotted owl habitat in the eastern Cascades, Washington. We used Akaike's Information Criteria (AIC) to determine the best models give the available data structure. Models are ranked in this list according to Δ_i value. In the activity center models, sample size was $n = 227$ (used) and $n = 241$ (available). In the reproductive site models, sample size was $n = 124$ (used) and $n = 241$ (available).

Model #	Model variables	AIC	Δ_i	w_i
Activity centers				
AC2	Forgroup + canopy + size + slope	534.3	0	0.5979
AC1	Forgroup + canopy + size + aspect + slope	535.1	0.8	0.4008
AC4	Canopy + size + slope	546.7	12.4	0.0012
AC5	Canopy + size	555.1	20.8	<0.0001
AC3	Forgroup + aspect + slope	642.6	108.3	<0.0001
AC6	Forgroup + aspect	650.8	116.5	<0.0001
AC7	Aspect	655.9	121.6	<0.0001
Reproductive sites				
R2	Forgroup + canopy + size + slope	386.1	0	0.7679
R1	Forgroup + canopy + size + aspect + slope	388.5	2.4	0.2312
R4	Canopy + size + slope	399.9	13.8	0.0008
R5	Canopy + size	411.5	25.4	<0.0001
R3	Forgroup + aspect + slope	456.3	70.2	<0.0001
R6	Forgroup + aspect	467.9	81.8	<0.0001
R7	Aspect	475.8	89.7	<0.0001

Table 3
Values of β, SE, and P for influential habitat variables in the top-ranked models for Northern spotted owl activity centers and reproductive sites in the eastern Cascades, Washington.

Covariate	Activity center models		Reproductive site models	
	β and SE	P	β and SE	P
Canopy (10–40%)	-0.9636 ± 0.4028	0.0167	-1.1859 ± 0.5433	0.290
Canopy (40–60%)	-0.8449 ± 0.3675	0.0215	-0.7444 ± 0.4733	0.1158
Forgroup (dry)	0.4150 ± 0.1115	0.0002	0.5085 ± 0.1303	<0.0001
Size (small)	-0.0771 ± 0.2141	0.7186	0.1761 ± 0.2386	0.4605
Size (medium)	-0.4261 ± 0.1776	0.0165	-0.4877 ± 0.2108	0.0207
Slope (flat)	-1.0168 ± 0.4697	0.0304	-1.5170 ± 0.8090	0.0608
Slope (gentle)	0.0411 ± 0.2431	0.8657	-0.0037 ± 0.3597	0.9918
Slope (moderate)	0.7832 ± 0.2165	0.0003	1.1222 ± 0.3205	0.0005

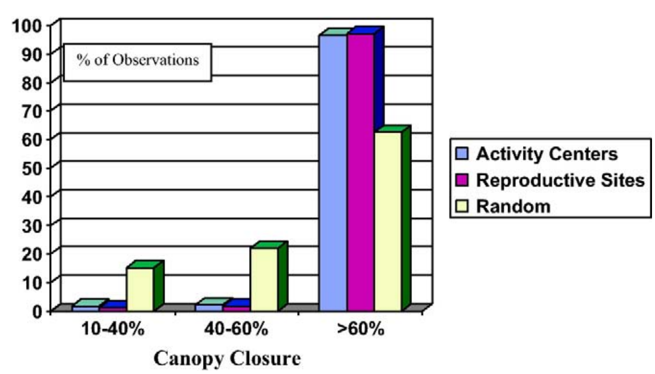

Fig. 3. The canopy closure classes associated with 227 Northern spotted owl activity centers, 124 reproductive sites, and 240 random locations in the eastern Cascades, Washington.

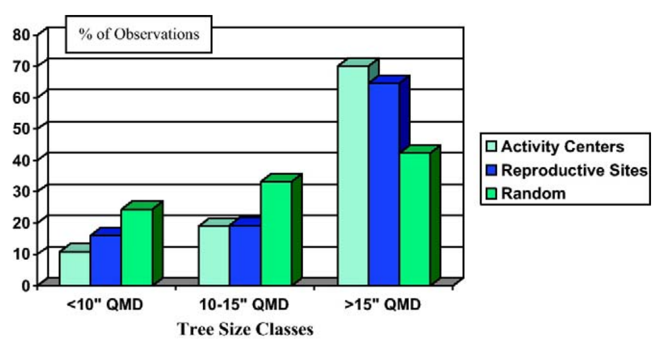

Fig. 4. The tree size classes associated with 227 Northern spotted owl activity 1 centers, 124 reproductive sites, and 240 random locations in the eastern Cascades, Washington.

classes (Fig. 4), and flat or steep slopes (Fig. 5). There were also some interesting differences between spotted owl activity centers and reproductive sites. For example, a higher proportion of the activity centers in dry forest were reproductive (Table 3 and Fig. 2), and a higher proportion of the reproductive sites were associated with moderate slopes compared to all of the activity centers (Table 3 and Fig. 5).

The cross-validation of model R2 showed that the model was relatively stable to changes in underlying data. The maximum likelihood estimates for the model variables varied little and the resulting cross-validation AIC scores were all less than the AIC score for the original model (Table 4). These results suggest that the R2 model should be useful in predicting the occurrence of suitable spotted owl nesting habitat.

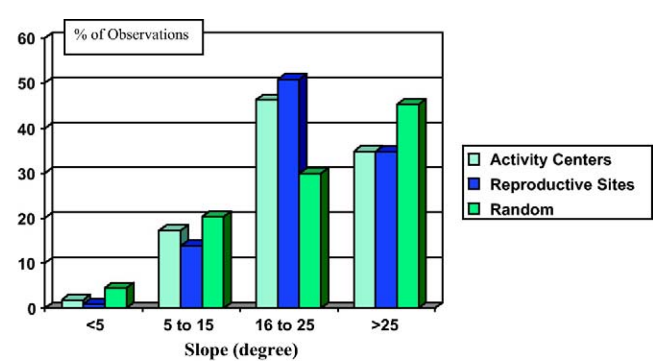

Fig. 5. The tree slope classes associated with 227 Northern spotted owl activity centers, 124 reproductive sites, and 240 random locations in the eastern Cascades, Washington.

Table 4
Results of 10-fold cross-validation of the top-ranked model for Northern spotted owl habitat in the eastern Cascades, Washington. Range of maximum likelihood estimate values and AIC scores for the cross-validation runs and the original model are presented.

Model	Maximum likelihood estimate (range)								
	DFG	C10–40	C40–60	SSmall	SMed	SlFlat	SlGentle	SlMod	AIC
C–V	0.48–0.52	−0.74 to −1.67	−0.48 to −1.46	0.04–0.27	−0.41 to −0.61	−1.40 to −1.66	−0.16 to 2.68	1.05–3.87	360–373
2	0.51	−1.18	−0.74	0.17	−0.49	−1.52	−0.004	1.12	386.1

We developed classes of habitat suitability using habitat variables identified from our habitat modeling. The habitat suitability classes were:

- High suitability = >60% canopy closure, >15″ Quadratic Mean Diameter (QMD) tree size, 16–25% slope.
- Moderate suitability = >60% canopy closure, >15″QMD tree size, 5–15% slope.
- Low suitability = >60% canopy closure, >15″ QMD tree size, flat and >25% slope.

Based on our habitat suitability map, 38% of the dry forest suitable spotted owl habitat was categorized as high suitability, 42% was moderate suitability, and 20% as low suitability. In the wet forest, 39% of the suitable spotted owl habitat was high suitability, 39% was moderate suitability, and 22% low suitability. The fuels treatment prioritization process resulted in 38% of the dry forest being high priority for treatment, 49% being moderate priority, and 13% being low priority. In the wet forest types, 7% was identified as high priority, 30% as moderate priority, and 63% as low priority.

When the spotted owl habitat suitability categories were intersected with the fuels treatment priority rankings, we found, as expected, that high suitability spotted owl habitat and high priority fuels treatments overlapped greater in the dry forest types than in the wet forest types (Table 5). About 34% of the high suitability spotted owl habitat in dry forest is also identified as moderate or high priority for fuels treatments. This compares to only 16% in the wet forest types. Conversely, 35% of the low suitability spotted owl habitat was identified as moderate or high priority for fuels treatment in the dry forest (Table 5).

4. Discussion

We present a relatively simple empirical model of spotted owl habitat for the eastern Cascades of Washington that we assessed using a cross-validation approach because we did not have an independent dataset within similar habitats to test our model in a more rigorous fashion (Burnham and Anderson, 1998; Zabel et al., 2003). However, our findings provide the "best model, given the data" and should be interpreted with this in mind (Burnham and Anderson, 1998).

Table 5
Matrix of the amount and proportion of high, moderate, and low suitability Northern spotted owl habitat within high, moderate and low fuels treatment priority areas for eastern Cascades, Washington.

Spotted owl habitat suitability	Fuels treatment priority		
	High	Moderate	Low
Dry forest			
High	27,743 (15%)	34,947 (19%)	7238 (4%)
Moderate	13,902 (8%)	17,746 (10%)	4449 (2%)
Low	28,195 (15%)	36,796 (20%)	11,761 (6%)
Wet forest			
High	8454 (3%)	34,807 (13%)	63,957 (23%)
Moderate	4681 (2%)	18,302 (7%)	37,976 (14%)
Low	7049 (2%)	28,991 (10%)	70,463 (26%)

We found that the variables most important in our model of spotted owl habitat were also variables described as important in other empirical studies. These included high canopy closure (Buchanan et al., 1995; Buchanan and Irwin, 1998), and large tree size (Buchanan et al., 1995; Everett et al., 1997). In addition, we found that forest group, specifically dry forest, and slope steepness (Singleton et al., 2010) were important variables associated with spotted owl habitat.

The association of spotted owls with dry forests and moderate slope steepness warrants further discussion. Typically, spotted owls have been associated with late-successional forests that occur within moist forest types (Thomas et al., 1990; Davis and Lint, 2005; USFWS, 2008), more closely resembling west-side forest conditions. Recent studies on barred owls (*Strix varia*) in the central and eastern Cascades have shown that barred owls are found at high densities on wetter portions of the forest (Herter and Hicks, 2000; Singleton et al., 2010). In addition, barred owls have been shown to select valley bottoms and gentle slopes within moist and dry forests (Herter and Hicks, 2000; Pearson and Livezey, 2007; Singleton et al., 2010). Additional research is needed to determine whether competition associated with the invasion of the barred owl results in increased importance, to Northern spotted owls, of dry forest with moderate slope steepness. Regardless, >50% of the known spotted owl locations on the Okanogan-Wenatchee National Forest occur within dry and mesic forests, indicating their importance for the conservation of spotted owls (Gaines, 2001).

Several authors have discussed issues concerning the sustainability of Northern spotted owl habitat within dry forests (Agee and Edmunds, 1992; Buchanan et al., 1995; Gaines et al., 1997; Gaines, 2001; Everett et al., 1997). We provide a quantitative evaluation of the potential overlap between dry forest spotted owl habitat and priority areas for fuels treatments. As expected, there is a high degree of overlap between the best dry forest spotted owl habitat and moderate-high priority fuel treatment areas (34% overlap; Table 5). However, there is also room for accomplishing multiple objectives if one considers a landscape perspective (the overlap of low quality spotted owl habitat and moderate-high priority fuels treatment areas is 35%; Table 5). Our results are very similar to those presented for the Mexican spotted owl (*Strix occidentalis lucida*) in southwestern US ponderosa pine forests where potential conflicts between forest restoration and maintaining spotted owl habitat represented only about 1/3 of the study region (Prather et al., 2008).

Fire model simulations have suggested that treating 20–22% of an area is the minimum amount of treatment that substantially alters landscape fire behavior given that treatment placement is optimized (Finney, 2001; Finney et al., 2006; Ager et al., 2007; Lehmkuhl et al., 2007). Habitat protection for the Northern spotted owl has been identified as a potential constraint that could limit the optimization of treatment location (Collins et al., 2010). However, treatment areas could take advantage of portions of dry forest landscapes that either do not provide spotted owl habitat or that have lower suitability habitat. This emphasizes the important need for tools that provide managers with information on how to maximize the effectiveness of fuels treatments while minimizing impacts to habitat (Ager et al., 2007; Lehmkuhl et al., 2007; Kennedy et al., 2008). Additionally, it may be possible to implement some types of fuel treatments within spotted owl habitat with limited effect on owl reproduction (Lee and Irwin, 2005), although we suggest this would best be done within the context of an adaptive management experiment.

The current conservation plan for Northern spotted owls on federal lands relies on a network of habitat reserves described in the Northwest Forest Plan (USDA and USDI, 1994). In contrast, the Northern Spotted Owl Recovery Plan outlines an approach in which spotted owl habitat objectives are embedded within a landscape level ecosystem restoration strategy for the fire-prone forests of eastern Washington and Oregon (USFWS, 2008). This strategy, based on the recommendations described in Courtney et al. (2008), recognizes the role of fire as a major disturbance in dry forests on the east-side of the Cascades. The strategy recognizes that fire will have a significant impact on the availability of roosting and nesting habitat for the recovery and conservation of the Northern spotted owl (see Halupka, 2001), especially in light of climate change (Westerling et al., 2006). In addition, recent research suggests that dry forests may play an increasingly important role in the long-term conservation of the spotted owl relative to competition from the sympatric barred owl (Singleton et al., 2010). This possibility increases the urgency of finding ways to address the management dilemma of retaining spotted owl habitat while restoring dry forest sustainability and resiliency.

Based on our research and experience, and after reviewing the Northern spotted owl recovery plan (USFWS, 2008) and recommendations from Courtney et al. (2008), we outline plan components for managers to consider in the development of a conservation strategy for Northern spotted owls in the eastern Cascades. These components may have relevance to others trying to integrate ecosystem restoration and fire management with the conservation of rare or endangered species.

(1) *Ecosystem restoration*. The overarching emphasis for a strategy should be on ecosystem restoration applied at the landscape scale (Franklin et al., 2008; North et al., 2009; Gaines et al., 2010). The focus on ecosystem restoration is to assure that: (a) no single resource (e.g., fuels reduction) is over emphasized (Brown et al., 2004; DellaSala et al., 2004; Noss et al., 2006) and (b) so that ecosystem processes and functions (e.g., habitat for species such as the white-headed woodpecker, *Picoides albolarvatus*) are addressed (Lehmkuhl et al., 2007).
(2) *Landscape perspective*. The landscape considered for restoration needs to be large enough to absorb the effects of wildfire disturbances and not limited to a subset of the landscape (e.g., reserves vs matrix). In addition, we do not yet know whether Northern spotted owls can persist on landscapes in the presence of barred owls (Singleton et al., 2010) making the placement of reserves challenging.
(3) *Key habitat elements*. To accomplish ecosystem restoration objectives and increase the potential for meeting spotted owl recovery goals (USFWS, 2008), managers may consider the following when evaluating dry and mesic forest landscapes: (a) restoration treatments should retain and develop large and old trees important for a variety of ecosystem functions (DellaSala et al., 2004; Noss et al., 2006) (e.g., white-headed woodpecker habitat, future spotted owl habitat) and known to be below the historical range of variability (Hessburg et al., 1999; Franklin et al., 2008); (b) juxtapose existing and future spotted owl habitat with restoration treatments so as to reduce its susceptibility to high severity fire (Prather et al., 2008); (c) limit fire behavior that creates large high severity fire patches in areas historically dominated by low severity fire (Everett et al., 2000; Wright and Agee, 2004; Hessburg et al., 2007); and (d) high severity fire in the appropriate landscape context (e.g., moderate to high elevation forests) (Brown et al., 2004) provides habitat for fire-dependent species and may function as foraging habitat for spotted owls (Bond et al., 2009).
(4) *Range of variation*. Use both the historical and future the range of variation from mixed-severity landscapes (Hessburg et al., 2007) to guide landscape (e.g., proportions of cover types and structure classes) (Agee, 2003b; Reynolds and Hessburg, 2005; Hessburg et al., 2007; Gartner et al., 2008) and stand level (e.g., density and spatial arrangement of large and old trees and snags) (Harrod et al., 1998; Harrod et al., 1999; Youngblood et al., 2004) restoration treatments. Using the concept of the future range of variability would incorporate likely effects of climate change (Gartner et al., 2008).
(5) *Monitoring and adaptive management*. The strategy needs to be framed within an adaptive management context allowing for adequate monitoring and feedback mechanisms for managers to make needed adjustments (Lee, 1993; DellaSala et al., 2004; Courtney et al., 2008).

References

Agee, J.K., Edmunds, R.L., 1992. Forest protection guidelines for the northern spotted owl. In: USDI (Ed.), Recovery Plan for the Northern Spotted Owl-Final Draft, vol. 2. U.S. Gov. Print. Off, Washington, DC, pp. 181–244.

Agee, J.K., 1993. Fire Ecology of the Pacific Northwest forests. Island Press, Washington, DC.

Agee, J.K., 2003a. Burning issues in fire: will we let the coarse filter operate? Tall Timbers Research, Miscellaneous Publication No. 13.

Agee, J.K., 2003b. Historical range of variability in eastern Cascades forests, Washington, USA. Landscape Ecology 18, 725–740.

Ager, A.A., Finney, M.A., Kerns, B.K., Maffei, H., 2007. Modeling wildfire risk to northern spotted owl (Strix occidentalis caurina) habitat in Central Oregon, USA. Forest Ecology and Management 246, 45–56.

Anderson, D.R., Link, W.A., Johnson, D.K., Burnham, K.P., 2001. Suggestions for presenting the results of data analysis. Journal of Wildlife Management 65, 373–378.

Anderson, D.R., Burnham, K.P., 2002. Avoiding pitfalls when using information-theoretic methods. Journal of Wildlife Management 66, 912–918.

Anderson, H.E., 1982. Aids to Determining Fuel Models for Estimating Fire Behavior. USDA, Forest Service, General Technical Report INT-122.

Anthony, R.G., Forsman, E.D., Franklin, A.B., et al., 2006. Status and trends in demography of northern spotted owls, 1985–2003. Wildlife Monographs 163, 1–48.

Bond, M.L., Gutierrez, R.J., Franklin, A.B., LaHaye, W.S., May, C.A., Seamans, M.E., 2002. Short-term effects of wildfires on spotted owl survival, site fidelity, mate fidelity, and reproductive success. Wildlife Society Bulletin 30 (4), 1022–1028.

Bond, M.L., Lee, D.E., Siegal, R.B., Ward Jr., J.P., 2009. Habitat use and selection by California spotted owls in a postfire landscape. Journal of Wildlife Management 73, 1116–1124.

Brown, R.T., Agee, J.K., Franklin, J.F., 2004. Forest restoration and fire: principles in the context of place. Conservation Biology 18, 903–912.

Buchanan, J.B., Irwin, L.L., McCutchen, E.L., 1995. Within-stand nest site selection by spotted owls in the eastern Washington Cascades. Journal of Wildlife Management 59 (2), 301–310.

Buchanan, J.B., Irwin, L.L., 1998. Variation in spotted owl nest site characteristics within the Eastern Cascade Mountains Province in Washington. Northwest Naturalist 79, 33–40.

Burnham, K.P., Anderson, D.R., 1998. Model selection and inference. Springer-Verlag, New York, NY.

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multi-Model Inference: a Practical Information-Theoretic Approach, 2nd ed. Springer-Verlag, New York, USA.

Collins, B.M., Stephens, S.L., Moghaddas, J.J., Battles, J., 2010. Challenges and approaches in planning fuel treatments across fire-excluded forested landscapes. Journal of Forestry (January/February), 24–31.

Courtney, S.P., Carey, A.B., Cody, M.L., Engel, K., Fehring, K.E., Franklin, J.F., Fuller, M.R., Gutierrez, R.J., Lehmkuhl, J.F., Hemstrom, M.A., Hessburg, P.F., Stephens, S.L., Sztukowski, L.A., Young, L., 2008. Scientific Review of the Draft Northern Spotted Owl Recovery Plan and Reviewer Comments. Sustainable Ecosystems Institute, Portland, OR.

Davis, R., Lint, J., 2005. Chapter 3: habitat status and trend. In: Lint, J. (Ed.), Status and Trends of Northern Spotted Owl Populations and Habitat. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-648, pp. 21–82.

DellaSala, D.A., Williams, J.E., Williams, C.D., Franklin, J.F., 2004. Beyond smoke and mirrors: a synthesis of fire policy and science. Conservation Biology 18, 976–986.

Driscoll, D.A., Lindenmayer, D.B., Bennett, A.F., Bode, M., Bradstock, R.A., Cary, G.J., Clarke, M.F., Dexter, N., Fensham, R., Friend, G., Gill, M., James, S., Kay, G., Keith, D.A., MacGregor, C., Russell-Smith, J., Salt, D., Watson, J.E.M., Williams, R.J., York, A., 2010. Fire management for biodiversity conservation: key research questions and our capacity to answer them. Biological Conservation 143, 1928–1939.

Dunk, J.R., Zielinski, W.J., Preisler, H.K., 2004. Predicting the occurrence of rare mollusks in northern California forests. Ecological Applications 14 (3), 713–729.

Elliot, B., 1985. Changes in distribution of owl species subsequent to habitat alteration by fire. Western Birds 16, 25–28.

Everett, R., Schellhaas, D., Spurbeck, D., Ohlson, P., Keenum, D., Anderson, T., 1997. Structure of northern spotted owl nest stands and their historical conditions on the eastern slope of the Pacific Northwest Cascades, USA. Forest Ecology and Management 94, 1–14.

Everett, R.L., Schellhaas, R., Keenum, D., Spurbeck, D., Ohlson, P., 2000. Fire history in the ponderosa pine/Douglas-fir forests on the east slope of the Washington Cascades. Forest Ecology and Management 129, 207–225.

Finney, M.A., 2001. Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. Forest Science 47, 219–228.

Finney, M.A., Seli, R.C., McHugh, C.W., Agar, A.A., Bahro, B., Agee, J.K., 2006. Simulation of long-term landscape-level fuel treatments on large fires. In: Andrews, P.L., Butler, B.W. (Eds.), Fuels Management – How to Measure Success. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, RMRS-P-41, pp. 125–147.

Forsman, E.D., 1983. Methods and Materials for Locating and Studying Spotted Owls. USDA Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-162, 8p.

Franklin, J.F., Hemstrom, M.A., VanPelt, R., Buchanan, J.B., 2008. The Case for Active Management of Dry Forest Types in eastern Washington: Perpetuating and Creating Old Forest Structures and Functions. Washington State Department of Natural Resources, Olympia, WA.

Gaines, W.L., Strand, R.A., Piper, S.D., 1997. Effects of the Hatchery Complex fires on northern spotted owls in the eastern Washington Cascades. In: Proceedings-Fire Effects on Rare and Endangered Species and Habitats, Coeur d'Alene, Idaho, pp. 123–129.

Gaines, W.L., 2001. Disturbance ecology, land allocations, and wildlife management. In: Proceedings of the Management of Fire Maintained Ecosystems Workshop: May 23–24, Whistler, British Columbia, pp. 29–34.

Gaines, W.L., Lyons, A.L., Sprague, A., 2005. Predicting the occurrence of a rare mollusk in the dry forests of north-central Washington. Northwest Science 79 (2–3), 99–105.

Gaines, W.L., Harrod, R.J., Dahlgreen, M., Thomas, C., Dickinson, J., Hutchinson, M., 2010. The Okanogan-Wenatchee National Forest Restoration Strategy: Adaptive Ecosystem Management to Restore Landscape Resiliency. USDA Forest Service, Pacific Northwest Region, Okanogan-Wenatchee National Forest, Wenatchee, Washington, 101pp.

Gartner, S., Reynolds, K.M., Hessburg, P.F., Hummel, S., Twery, M., 2008. Decision support for evaluating landscape departure and prioritizing forest management activities in a changing environment. Forest Ecology and Management 256, 1666–1676.

Halupka, K., 2001. Environmental Baseline Update for the Northern Spotted Owl on the Wenatchee National Forest and the Washington Eastern Cascades Physiographic Province. USFWS, Wenatchee, WA, 61p.

Hanson, C.T., Odion, D.A., DellaSala, D.A., Baker, W.L., 2009a. Overestimation of fire risk in the Northern spotted owl recovery plan. Conservation Biology 23, 1314–1319.

Hanson, C.T., Odion, D.A., DellaSala, D.A., Baker, W.L., 2009b. More-comprehensive recovery actions for Northern spotted owls in dry forests: reply to Spies et al. Conservation Biology 24, 334–337.

Harrod, R.J., Gaines, W.L., Hartl, W.E., Camp, A., 1998. Estimating Historical Snag Density in Dry Forests East of the Cascade Range. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon, PNW-GTR-428.

Harrod, R.J., McRae, B.H., Hartl, W.E., 1999. Historical stand reconstruction in ponderosa pine forests to guide silvicultural prescriptions. Forest Ecology and Management 114, 433–446.

Healey, S.P., Cohen, W.B., Spies, T.A., Moeur, M., Pflugmacher, D., Whitley, M.G., Lefsky, M., 2008. The relative impact of harvest and fire upon landscape-level dynamics of older forests: lessons from the Northwest Forest Plan. Ecosystems 11, 1106–1119.

Herter, D.R., Hicks, L.L., 2000. Barred owl and spotted owl populations and habitat in the central Cascade Range of Washington. Journal of Raptor Research 34 (4), 279–286.

Hessburg, P.F., Salter, R.B., Jones, K.M., 2007. Re-examining fire severity relations in pre-management era mixed conifer forests: inferences from landscape patterns of forest structure. Landscape Ecology 22, 5–24.

Hessburg, P.F., Agee, J.K., Franklin, J.F., 2005. Dry forests and wildland fires of the inland Northwest, USA: contrasting the landscape ecology of pre-settlement and modern eras. Forest Ecology and Management 211 (1), 117–139.

Hessburg, P.F., Smith, B.G., Kreiter, S.D., Miller, C.A., Salter, R.B., McNicoll, C.H., Hann, W.J., 1999. Historical and Current Forest and Range Landscapes in the Interior Columbia River Basin and Portions of the Klamath and Great Basins. Part 1. Linking Vegetation Patterns and Landscape Vulnerability to Potential Insect and Pathogen Disturbances. USDA Forest Service, Pacific Northwest Research Station, General Technical Report, PNW-GTR-458.

Kennedy, M.C., Ford, E.D., Singleton, P., Finney, M., Agee, J.K., 2008. Informed multi-objective decision-making on environmental management using parent optimality. Journal of Applied Ecology 45, 181–192.

Landsberg, J.D., Lehmkuhl, J.F., 1997. Tigers, rhinos and fire management in India. In: Proceedings-Fire Effects on Rare and Endangered Species and Habitats, Coeur d'Alene, Idaho, pp. 101–108.

Lee, D.C., Irwin, L.L., 2005. Assessing risks to spotted owls from forest thinning in fire-adapted forests of the western United States. Forest Ecology and Management 211, 191–209.

Lee, K.N., 1993. Compass and Gyrospcope: Integrating Science and Politics for the Environment. Island Press, Washington, DC.

Lehmkuhl, J.F., Kennedy, M., Ford, E.D., Singleton, P.H., Gaines, W.L., Lind, R.L., 2007. Seeing the forest for the fuels: integrating ecological values and fuels management. Forest Ecology and Management 246, 73–80.

Lillybridge, T.R., Kovalchik, B.L., Williams, C.K., Smith, B.G., 1995. Field Guide for Forested Plant Associations of the Wenatchee National Forest. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-359, 337p.

MacCracken, J.G., Boyd, W.C., Rowe, B.S. 1996. Forest health and spotted owls in the eastern cascades of Washington. In: K.G. Wadsworth, R.E. McCabe, (Eds.) Facing realities in resource management. Transactions of the North American Wildlife and Natural Resources Conference 61(7), pp. 519–527.

McGarigal, K., Marks, B.J., 1993. FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure. USDA, For. Gen. Tech. Rep. PNW-GTR-351.

Myers, R.L., 1997. Designing fire regimes for biodiversity conservation. In: Proceedings-Fire Effects on Rare and Endangered Species and Habitats, Coeur d'Alene, Idaho, p. 1.

Nieman, K.E., 1998. Forest Structural Stage and Canopy Closure Mapping of the Central East Cascade Ecoregion of Washington. Resource Analysis and Management, Bellevue, WA.

North, M., Stine, P., O'Hara, K., Zielinski, W., Stephens, S., 2009. An Ecosystem Management Strategy for Sierran Mixed-Conifer Forests. USDA Forest Service, Pacific Southwest Research Station, General Technical Report, PSW-GTR-220.

Noss, R.F., Franklin, J.F., Baker, W.L., Schoennagel, T., Boyle, P.B., 2006. Managing fire-prone forests in the western United States. Frontiers in Ecology and Environment 4 (9), 481–487.

Pearson, R.R., Livezey, K.B., 2007. Spotted owls, barred owls, and late-successional reserves. Journal of Raptor Research 41 (2), 156–161.

Prather, J.W, Noss, R.F., Sisk, T.D., 2008. Real versus perceived conflicts between restoration of ponderosa pine forests and conservation of the Mexican spotted owl. Forest Policy and Economics 10, 140–150.

Reynolds, K.M., Hessburg, P.F., 2005. Decision support for integrated landscape evaluation and restoration planning. Forest Ecology and Management 207, 263–278.

Roberts, S.L. 2008. The effects of fire on California spotted owls and their mammalian prey in central Sierra Nevada, California. Ph.D. Dissertation, University of California, Davis. 120 pp.

Saaty, T.L., 2001. Decision Making for Leaders. The Analytic Hierarchy Process for Decisions in a Complex World. RWS Publications, Pittsburg, PA.

Singleton, P.H., Lehmkuhl, J.F., Gaines, W.L., Graham, S.A., 2010. Barred owl space use and habitat selection in the eastern Cascades, Washington. Journal of Wildlife Management 74 (2), 285–294.

Spies, T.A., Hemstrom, M.A., Youngblood, A., Hummel, S., 2006. Conserving old-growth forest diversity in disturbance-prone landscapes. Conservation Biology 20, 351–362.

Spies, T.A., Miller, J.D., Buchanan, J.B., Lehmkuhl, J.F., Franklin, J.F., Healey, S.P., Hessburg, P.F., Safford, H.D., Cohen, W.B., Kennedy, R.S.H., Knapp, E.E., Agee, J.K., Moeur, M., 2009. Underestimating risks to the Northern spotted owl in fire-prone forests: response to Hanson et al. Conservation Biology 24, 330–333.

Tari, M. 2007. A Geographic Information Systems analysis of northern spotted owl habitat in eastern Washington. M.S. Thesis, Central Washington University, Ellensburg.

Thomas, J.W., Forsman, E.D., Lint, J.B., Meslow, E.C., Noon, B.R., Verner, J., 1990. A Conservation Strategy for the Northern Spotted Owl. Interagency Scientific Committee to Address the Conservation of the Northern Spotted Owl. USDA Forest Service, USDI Bureau of Land Management, USDI Fish and Wildlife Service, and USDI National Park Service, Portland, Oregon, 458 pp.

U.S. Department of Agriculture (USDA), U.S. Department of Interior (USDI), 1994. Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl. USDA Forest Service, Portland, Oregon and USDI Bureau of Land Management, Portland, Oregon.

U.S. Fish and Wildlife Service (USFWS), 1992. Protocol for Surveying Proposed Management Activities that may Impact Northern Spotted Owls. USFWS, Portland, OR.

U.S. Fish and Wildlife Service (USFWS), 2008. Final Recovery Plan for the Northern Spotted Owl, Strix occidentalis caurina. USFWS, Portland, Oregon, 170 p.

U.S. Forest Service (USFS), 1997. Wenatchee National Forest Late-Successional Reserve Assessment. USFS, Wenatchee, WA.

U.S. Forest Service (USFS), 2001. Strategy for the Management of Dry Forest Vegetation on the Okanogan and Wenatchee National Forests. USDA Forest Service, Okanogan-Wenatchee National Forest, Wenatchee, Washington, 45 pp.

Westerling, A.L., Hidalgo, H.G., Cayan, D.R., Swetnam, T.W., 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science 313, 940–943.

Wright, C.S., Agee, J.K., 2004. Fire and vegetation history in the eastern Cascade Mountains. Washington. Ecological Applications 14 (2), 443–459.

Youngblood, A., Max, T., Coe, K., 2004. Stand structure in eastside old-growth ponderosa pine forests of Oregon and northern California. Forest Ecology and Management 199, 191–217.

Zabel, C.J., Dunk, J.R., Stauffer, H.B., Roberts, L.M., Mulder, B.S., Wright, A., 2003. Northern spotted owl habitat models for research and management application in California. Ecological Applications 13 (4), 1027–1040.